THE UTILIZATION OF INULIN FOR GROWTH BY THE YOUNG WHITE RAT

By ADELAIDA BENDAÑA

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in the University of Michigan

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THE UTILIZATION OF INULIN FOR GROWTH BY THE YOUNG WHITE RAT

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ONE FIGURE

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Despite much experimental study, the value of inulin for the nutrition of the higher forms is yet to be demonstrated satisfactorily. It is recognized that enzymes, which convert inulin to fructose, can hardly be significant factors in the activity of the secretions of the gastro-intestinal canal of the higher forms, but that under certain conditions, the gastric acidity may be sufficiently high to cause the hydrolysis of inulin to fructose to a limited extent. The microflora of the intestine attack inulin readily, but the chief products of this fermentation are fatty acids of low molecular weight and not carbohydrates (Ashe and Bing, '34). Absorption and utilization of inulin without previous hydrolysis in the gastro-intestinal tract has also been suggested (Heupke and Blanckenburg, '34), but in the light of experiments on the fate of inulin introduced parenterally, this seems improbable. McCance and Lawrence ('29) have presented an excellent critical review of the general problem of inulin utilization.

The chief evidence in support of utilization of inulin is to be obtained from certain experiments in which a deposition of liver glycogen has been observed to follow inulin feeding and from increases in respiratory quotients after the administration of inulin. In most cases, the increases in liver glycogen after ingestion of inulin are slight, particularly

when compared with the values obtained after the feeding of comparable amounts of readily utilized carbohydrates, fructose or glucose. The fallacies of the evidence based on the respiratory quotient are well presented by McCance and Lawrence ('29).

In addition to lack of satisfactory direct experimental methods and to difficulties in the interpretation of data, still further confusion has resulted from the failure to recognize the variability of the material used as a source of the carbohydrate. It is known that the chemical and physical properties of inulins of different botanical origin vary (Yanovsky and Kingsbury, '31, '33), and that fructosans, other than inulin, are present in plant tissue. Moreover the relative amounts of inulin and the other fructosans, the so-called inulides, vary with the season. It can hardly be expected, therefore, that the results obtained by the administration of a tuber (e.g., Jerusalem artichoke), which contains inulin and other fructosans, will be comparable with those obtained with inulin isolated from the same source. In fact inulins of different origin, although prepared under uniform conditions, may not be chemical individuals, and it is preferable in the light of our present knowledge to include in the inulin group all complex anhydrides of fructose (Yanovsky and Kingsbury, '31).

One direct method of study, which is concerned with the calorific value of inulin in the diet of the young white rat, has not been employed extensively. If inulin is used to any significant extent, it should be able to supply energy and thus promote the growth of young white rats when supplied either as the sole source of carbohydrate, or as a supplement to readily available carbohydrates in a low calorie diet adequate in all other known essential elements. The present study employs this procedure and approaches the inulin problem by a consideration of the rate of growth of young white rats maintained on a low calorie diet with sucrose or fructose as the source of carbohydrate in the basal diet and inulin or inulin plus sucrose or fructose in the experimental diets.

Purified inulin from chicory, generously furnished through the courtesy of Dr. Elias Yanovsky of the carbohydrate division of the Bureau of Chemistry and Soils of the United States Department of Agriculture, was used in our studies.

The results have indicated some utilization of inulin as a source of energy for the growing white rat, a utilization, however, distinctly inferior to that of either sucrose or fructose. In common with other observers, we have noted that inulin, if ingested in considerable amounts, resulted in marked gas formation and disturbance of function of the gastro-intestinal canal. We feel that our data indicate that the isolated polysaccharide from chicory is of little dietetic value from the practical standpoint as a significant source of energy. Our results are at variance with those of certain Japanese investigators, which will be considered subsequently.

EXPERIMENTAL

The chicory inulin used in these studies contained 10 per cent of moisture and 0.09 per cent of ash and showed a specific rotation of $-33.9°$ (uncorrected for moisture or ash) when examined at 27° with sodium light.

Litter units of young white rats of 65 to 75 gm. weight were divided into control and experimental groups for the nutritional studies to be described. Attempts to use younger and smaller rats were unsuccessful since, even when relatively small amounts of inulin (1.5 gm.) were added as supplements to the basal diet, marked diarrhoea and distention of the intestines resulted and the animals died within a few days.

In preliminary experiments it was found that inulin was not satisfactory as the sole source of carbohydrate of the diet, that some readily utilizable carbohydrate must be supplied. The addition of 2.5 to 4.1 gm. of inulin to a basal diet containing no readily available sugar resulted in a rapid loss of weight and death within a few days. Death was presumably due to starvation and the marked distention of the intestines occasioned by the large amount of gas produced as a result of the fermentation of the inulin. The distention of

the abdomen was so marked that the animals could be readily distinguished from the controls. Diarrhoea and frequently bloody fecal masses were observed.

In the final series of experiments, basal low calorie diets containing a limited amount of sucrose (diet 10) or fructose (diet 12) were prepared to which extra carbohydrate in the form of sucrose, fructose or inulin was added for the experimental diets. The composition of these diets is presented in table 1.

TABLE 1

Basal and experimental diets

	10	10a	10c	11	12	12a	12c
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Casein	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Cod liver oil	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Lard	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Agar	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Salt mixture[1]	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Sucrose	1.5	1.5	3.0				
Inulin		1.5		1.5		1.5	
Fructose					1.5	1.5	3.0
Daily food intake	3.8	5.3	5.3	3.8	3.8	5.3	5.3
Daily calorie intake (calculated)	12.6	18.6[2]	18.6	12.6[2]	12.6	18.6[2]	18.6

[1] McCollum-Davis salt mixture no. 185.

[2] Calculated on the basis that 1 gm. of inulin supplies the same number of calories as 1 gm. sucrose or fructose.

In each series of experiments, the rats were placed in individual wire cages and given a fixed amount of food daily, 3.8 gm. for each of the animals receiving diets 10, 11 and 12, and 5.3 gm. for each of those receiving diets 10a, 12a, 12c and 10c. A supplement of 50 mg. of Harris yeast vitamin pill was given daily to each rat to supply the vitamin B complex. In two series of experiments a daily supplement of 100 mg. of the vitamin pill was given daily to each rat to see whether a larger amount of vitamin B would influence the growth of the rats. Water was given ad libitum. The rats were weighed every 3 days. Consumption of food was both rapid and complete. This was to be expected as the amount of food given daily to each rat was quite small (3.8 or 5.3 gm.).

Typical results obtained with various litter units are presented in table 2 and figure 1. The diets fed were essentially the same except for the content of carbohydrates. The basal diet, which furnished approximately 12.6 Cal., was calculated to be sufficient to maintain the animals at nearly constant

TABLE 2

Weight of rats fed low calorie diets and diets containing added carbohydrate. All feeding periods were of 60 days duration

SEX	DIET	WEIGHT		CHANGE IN WEIGHT
		Initial	Final	
Litter A				
		gm.	*gm.*	*gm.*
F	10	60.6	65.5	+ 4.9
F	10	71.5	81.5	+ 10.0
M	10	65.0	80.0	+ 14.5
F	11	69.0	62.5	— 6.5
M	11	76.0	62.0	— 14.0
F	11	76.0	57.5	— 18.5
F	10a	70.5	102.0	+ 31.5
M	10a	64.5	105.0	+ 40.5
F	10a	67.0	99.0	+ 32.0
F	10a	63.1	104.5	+ 41.4
Litter C				
F	10	71.0	74.0	+ 3.0
F	10	63.5	68.0	+ 4.5
M	10	68.5	79.5	+ 11.5
F	10a	77.0	98.5	+ 21.5
F	10a	71.0	86.5	+ 15.5
M	10c	82.5	119.8	+ 37.3
F	10c	72.0	113.5	+ 41.5
F	10c	74.2	107.3	+ 33.1

SEX	DIET	WEIGHT		CHANGE IN WEIGHT
		Initial	Final	
Litter B				
		gm.	*gm.*	*gm.*
F	12	70.0	75.0	+ 5.0
M	12	70.2	75.5	+ 5.3
M	12	64.5	81.0	+ 16.5
F	12	64.5	78.5	+ 14.0
M	12c	77.5	113.5	+ 36.0
F	12c	62.5	102.5	+ 40.0
F	12c	71.5	112.0	+ 40.5
M	12c	70.5	119.0	+ 49.0
F	12a	70.1	99.0	+ 28.9
F	12a	67.5	99.5	+ 32.0
M	12a	67.0	94.5	+ 27.0
Litter D				
M	12	60.8	67.5	+ 6.7
F	12	65.2	68.5	+ 3.3
F	12	59.0	68.5	+ 9.5
M	12	52.0	60.5	+ 8.5
F	12a	61.0	81.5	+ 20.5
M	12a	69.0	87.0	+ 18.0
M	12	73.2	87.5	+ 14.3
F	12	58.5	79.5	+ 21.0

weight. If the inulin were utilized to any significant extent, addition of 1.5 gm. of inulin daily (6 Cal.) should result in increased growth, since it was considered that the protein of the diet was adequate for animals of this weight. In the first series of experiments, in which sucrose served as the source of carbohydrate in the basal diet (diet 10), added inulin

(diet 10a) produced definite increases in weight (table 2, litters A and C), indicating utilization of the polysaccharide. Since inulin is a fructosan, it was considered desirable to supply fructose rather than sucrose as the source of carbohydrate in the basal diet (diet 12). Addition of inulin to this diet (diet 12a) also resulted in an increased rate of growth (table 2, litters B and D). It appeared that inulin was available as a source of energy to some extent.

In order to determine how the utilization of inulin compared with that of sucrose or fructose under our experimental

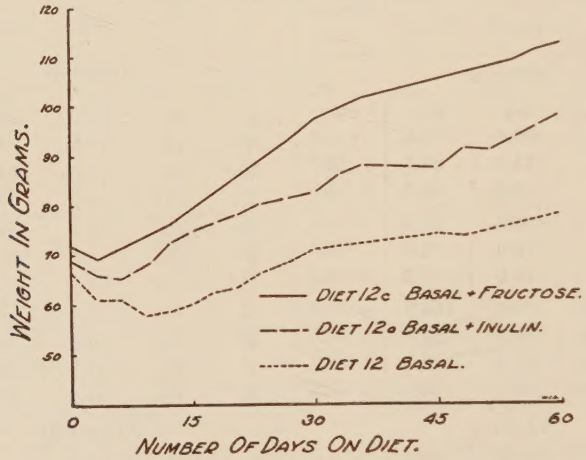

Fig. 1 Weight curves of rats receiving the basal low calorie diet and the basal diet supplemented by inulin and by fructose. The curves presented are averaged for three (diet 12a) and four (diets 12 and 12c) rats of the same litter.

conditions, sucrose (diet 10a) and fructose (diet 12c) were added to the basal diet in amounts comparable to the amount of the inulin added. It was observed that while, as already stated, rats fed the basal diets plus 1.5 gm. of inulin showed better growth than the control animals receiving the basal diet without supplement, the animals receiving the basal diet plus sucrose (litter C) or fructose (litter B) showed rates of growth distinctly superior to that of the inulin-fed rats. The figures show that although inulin may be utilized by the rat, the extent of utilization as measured by the growth response

is by no means comparable to that of either sucrose or fructose. The same conclusion is to be drawn from the typical growth curve presented in figure 1.

It has been stated previously that it was found necessary to include some readily utilizable carbohydrate in the diet and that when inulin was the sole source of carbohydrate, marked gastro-intestinal disturbances which terminated fatally within a few days resulted. With one litter only were we successful in continuing the use of the diet in which inulin was the sole source of the carbohydrate (diet 11) throughout the entire feeding period of 60 days. The results of this experiment are presented in table 2 (litter A). On the basal low calorie diet containing a limited amount of sucrose (diet 10), three animals gained an average of 9.8 gm. each in the 60-day period. When inulin served as the sole source of carbohydrate (diet 11), all the animals survived but lost weight at first rapidly, then more slowly (an average loss of weight of 13.0 gm.). When half of the inulin of diet 11 was replaced by sucrose (diet 10a), all the animals grew well, an average gain per rat of 36.3 gm. being recorded. The results with this litter are discussed in detail since these particular animals appeared to tolerate inulin unusually well and the group fed both sucrose and inulin showed growth superior to that obtained on inulin feeding with any other litter. These results show clearly that inulin alone as a source of carbohydrate is unsatisfactory, but that inulin as a supplement to a diet containing some other carbohydrate has a limited value.

Our results which indicate that the utilization of inulin as a source of energy by young white rats is limited and is distinctly inferior to that of sucrose or fructose are not in accord with the results of a few similar studies in the literature. Emerique ('25) in studies similar to those here reported was unable to observe any utilization of inulin by young white mice. One group of only three animals was studied however. Ariyama and Takahasi ('29) believed that the nutritive value of inulin was equal to that of starch, dextrin, sucrose or lactose. The small number of rats (two) used makes the

experimental results difficult to interpret. Narushima ('27) found that inulin was as effectively utilized by young white rats as was cornstarch, but was not as effectively utilized as fructose. It seems incredible that the addition of 0.8, 2.4 and 2.8 Cal. as fructose (i.e., 0.2, 0.6 and 0.7 gm.) to a basal diet furnishing 37 Cal. daily could lead to such marked increases in weight (37.5, 37.5 and 34.5 gm., respectively), while the animals on the basal diet gained only 8.5 gm. during the same experimental period of 33 days. These results are the more striking since these small variations in the calorific value of the diet markedly influenced the growth of animals weighing for the most part over 100 gm. at the beginning of the feeding periods. Our results are rather in harmony with previous work from this laboratory (Bodey, Lewis and Huber, '27) in which it was shown that the administration of inulin led to an increased storage of glycogen in fasting young white rats but that the storage of glycogen was much less marked than that observed when fructose was fed.

In conclusion we wish to emphasize that, while our evidence indicates that the organism of the young rat may utilize inulin as a source of energy to a limited degree, the experiments furnish no information as to how this energy is made available. The lack of a known effective mechanism for the hydrolysis of inulin to fructose in the gastro-intestinal tract of the higher forms and the marked intestinal fermentation observed suggest that the nutritive value of the inulin may be due to the absorption and utilization of organic acid or similar products formed in the intestine by the activities of microorganisms (Ashe and Bing, '34). In addition, it should be pointed out that the results of the investigation do not bear directly on the problem of the utilization of inulin-containing vegetables. Our investigations are concerned with the isolated polysaccharide, inulin, from a single botanical source, chicory,[1] and the results cannot be applied to the problem of

[1] We also prepared in this laboratory inulin from freshly dug dahlia tubers. A limited series of studies with dahlia inulin gave results comparable with those obtained with inulin from chicory.

the utilization of the mixture of fructosans, the inulides, present in the vegetables, the nature of which varies with the season and with the botanical species.

SUMMARY

1. Young white rats (65 to 75 gm.) were maintained upon a diet, whose limiting factor was a calorific one.

2. When extra calories in the form of inulin from chicory, sucrose, or fructose were supplied as a supplement to the basal diet, the rate of growth was increased. The utilization of inulin under these experimental conditions, as measured by the response in growth, was distinctly inferior to that of sucrose or fructose.

3. Inulin could not be effectively utilized by the young white rat as the sole source of carbohydrate since the marked intestinal fermentation of the polysaccharide caused distention of the intestine and usually death within a few days.

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